

Supporting Meaningful Revision of Scientific Ideas in an Online Genetics Unit

Abstract: This research investigates two ways to encourage revision of scientific essays in an online unit featuring dynamic models of genetic inheritance. Revising is difficult for students, due partly to lack of practice and guidance. Here we examine the effects of an essay annotator activity that models the essay revision process (*text*) compared to an activity in which students annotate screenshots of interactive models from the unit (*model*), designed to support gaining ideas from evidence. We found that all students, regardless of condition, improved in their ability to revise, but low prior knowledge students benefited more from the *text* annotator condition. We hypothesize that the *text* annotator activity made the process of revision more visible, illustrating how to better articulate ideas, and resulting in more frequent revisions and the addition of more new ideas.

Keywords: science, genetics, revision, models, technology, knowledge integration

Introduction

Complex scientific topics such as genetic inheritance are notoriously challenging for students; understanding inheritance requires integration of phenomena occurring at various levels, ranging from DNA, genes, and alleles to inheritance of chromosomes to phenotypic expression (Jacobson & Wilensky, 2006). Understandably, students have a difficult time constructing coherent explanations about complex topics, and they especially struggle with revising explanations after encountering new evidence (Berland & Reiser, 2009). Many students learn science concepts separately from the context of their prior knowledge and, as a result, often return to their naive initial ideas when asked to construct explanations later (Mercier & Sperber, 2011). This prompts the need to support students in integrating new scientific ideas with their prior knowledge. In this study, we compare two guidance activities designed to support meaningful revisions in genetics: the *text* annotator, designed to make the revision process more visible, and the *model* annotator, designed to reinforce interpretation of evidence from the output of genetics simulations and models.

Typically, students' revisions include only surface-level or grammatical fixes rather than integration of new content (Crawford et al., 2008; Bridwell, 1980), resulting in a collection of disconnected ideas (Rivard 1994). Since reading and writing in science are tied closely to inquiry and meaning-making (Cervetti & Pearson, 2012; Howard, 1988), it is important to expose students to good practices for writing about their ideas. Revision is also a prominent theme in the Next Generation Science Standards (NGSS), which is based upon the philosophy that students continually build on and revise their knowledge (NGSS Lead States, 2013). Several of the NGSS science and engineering practices describe an iterative process of incorporating new ideas and evidence into continually constructed scientific knowledge, including: *constructing explanations, engaging in argument from evidence, and obtaining, evaluating, and communicating information*.

We employ the knowledge integration (KI) framework for curriculum design and analysis of student work since it emphasizes eliciting and building on students' prior ideas, making it an ideal framework for promoting integrated revision (Linn & Eylon, 2011). The knowledge integration framework encourages the design of activities that help students add new ideas, distinguish among all their ideas (prior and added), and finally reflect on their understanding of the process they are learning about, in this case genetics. This framework has proven useful for helping students diagnose issues with their scientific ideas and making successful revisions in other contexts (Tansomboon, 2017). Within the knowledge integration framework, revising ideas can help students integrate new concepts, and may especially help students who come in with low prior knowledge (LPK). The revision process encourages students to distinguish which of their ideas are relevant and use evidence from models and simulations in the curriculum to support their explanations and arguments. Our goal in this work is to encourage revision to help students move beyond rote skills and towards purposeful and usable construction of knowledge.

The genetics unit employed in this study was designed according to the knowledge integration framework to promote building on prior knowledge (Linn et al. 2014). We elicit students' ideas through embedded essay questions in which students make predictions regarding DNA and inheritance of traits. We compare a text-annotator guidance activity (*text* condition) to an activity where students annotate screenshots of familiar interactive models (*model* condition). These conditions were designed these based on previous findings that annotating a fictional students' essay helped LPK students improve their own revisions (Author redacted for

blind review). The text annotator activity replicates this; it models the revision process, having students label a fictional student's essay to encourage integration of missing information into their own response (figure 1). Our previous work also found that directing students back to relevant models helped students gain more new ideas; the model annotator activity was designed to scaffold gaining more new ideas from the evidence in the models (figure 2). In terms of the knowledge integration framework, the *text* condition is designed to help students distinguish and connect ideas, while the *model* condition was designed to help add ideas that students might have missed. Each of these steps are important for overall student understanding, so our goal in this study is to determine which activities are more helpful for which types of students.

CRITIQUING PROBABILITY IDEAS

Another student, Jason, also wrote an essay about using a Punnett square, but his answer has some issues to fix. Take a look at Jason's essay below. Drag the labels onto the red underlined parts of his essay to suggest where he should add ideas or clarify what he means.

Q: Explain how you would use a Punnett square to figure out the probability of getting a certain genotype.

I would put the mom's alleles and the dad's alleles on the outside, and then fill in the squares with the genes. Each box shows a possible child that they could have. You can tell what the traits are from the letters. Then you get the probability of each one.

[How do you figure out the probability of a square?]

[How can you figure out the expression of the traits from the letters?]

[What does each square represent?]

Figure 1: Example revision guidance activity for the *text* annotator condition.

LABEL THE PUNNETT SQUARE

Drag the labels below to the correct place on the filled-out Punnett Square.

		Brown Eyed Mother	
		B	b
Brown Eyed Father	B	BB	Bb
	b	Bb	bb

[There is a 50% chance of getting this genotype]

[There is a 25% chance of getting this phenotype]

[The mother's dominant allele]

[The father's recessive allele]

Figure 2: Example revision guidance activity for the *model* annotator condition.

Methods

Participants and procedures

Six classes of 6th grade students (N=173) from one teacher participated in this study (94% non-white, 89% free/reduced lunch, 30% ELL). Students completed our 10-day Genetics and Simple Inheritance unit

during class periods, working individually on the pretest and posttest, and working in pairs or groups of 3 on the unit itself. We conducted analyses on all students. This study compares the effect of different guidance on the types of revisions students made. Students answered embedded essay questions throughout the unit, then participated in one of the two guidance activities (figures 1 and 2), then were prompted to revise their initial essay response immediately after (see Table 1 for outline of conditions). The revision prompt automatically imported students' initial essays for revision.

Table 1. Outline of a sample sequence of *text* and *model* conditions on embedded assessments.

Steps	<i>Text</i> Annotator	<i>Model</i> Annotator
Essay Prompt	Prompt: Explain how you would use a Punnett square to figure out the probability of getting a certain genotype.	
Students split randomly by WISE ID	<i>Text</i> annotator: Place pre-written labels on a fictional students' essay to show where ideas are missing.	<i>Model</i> annotator: Place prewritten labels on a screenshot of a model that students have already interacted with to show what parts of the model represent.
Revision Prompt	Revise: Now that you've learned a bit more about Punnett squares and probability, take some time to revise or improve your answers to these two questions from earlier.	

Curricular materials

This study employs a Web-based Inquiry Science Environment (WISE) curriculum on the topic of genetics and simple inheritance, corresponding to NGSS (MS-LS3) (NGSS 2013). It is built according to the Knowledge Integration (KI) framework, which elicits and builds upon student ideas to integrate new content, making it an ideal platform to explore revision guidance strategies (Liu et al. 2008). Computer simulations guide student pairs through activities where they combine alleles to see phenotypic expression patterns, explore their own inherited traits, predict their own genotypes, and examine their family histories. Students ask questions, use models, and construct arguments from evidence in accordance with NGSS science practices. The technological environment allows for interactive visualizations of concepts that are difficult to explore in real life, including the ability to try out different allele combinations and their outcomes. A significant feature of this unit includes regular opportunities for student pairs to discuss and revise their ideas after interacting with models, encouraging students to make significant connections. Student workgroups (2-3 students) were randomly assigned to one of the two guidance conditions (*text* annotator or *model* annotator) before being asked to revise their scientific explanations.

Assessments

This study included a pretest and posttest as measures of student knowledge integration before and after completing the unit. Three pre/post items were pooled for analysis, and generally prompted students to provide a written explanation that required synthesis of several genetics concepts. A revision question was also included on the pre/post test, asking students to revise their explanation after receiving new information about a pedigree (figure 3). This question allowed us to assess students' inherent ability to incorporate new knowledge in their scientific explanations and see improvement in revision skills based on our curriculum.

Two embedded essay revision assessments were of main interest in our analysis as well. The first (named *Siblings*) prompts: "Siblings look similar, but not exactly the same unless they are identical twins. If they inherited their DNA from the same parents, why don't siblings look exactly the same? Explain." This item was designed to elicit a wide range of understanding, including how chromosomes are passed from parent to child, independent assortment of alleles, and dominant and recessive expression patterns. The second item (named *Punnett Square*) prompts students to explain how they would calculate the probability of getting a certain genotype using a Punnett square; this requires understanding of genetics concepts as well as calculation and interpretation of probability of inheritance. Each student group answered each of these questions, received one of the two types of experimental guidance (*text* or *model* annotation), and were then prompted to revise (Table 1).

Analysis approach

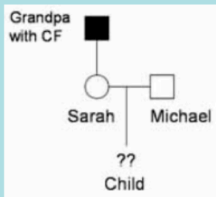
All essay responses (pre/posttest and embedded items, initial and revised essays) were scored using a 5-point Knowledge Integration (KI) scale to measure science understanding. KI rubrics reward making links between multiple normative science ideas (Linn & Eylon, 2011; Liu et al, 2008). The KI rubric for the *Punnett Square* item shows how scientific links are scored (Table 2). Multiple researchers co-develop the rubrics for each item and scoring of data was done by two researchers until a high degree of agreement was reached. For each revision item (pre/post and embedded), KI scores were given to both the initial and revised essays; revision gain was calculated by subtracting initial KI score from revised KI score for each of these items.

For some analyses, we categorized students that received a score of 1 or 2 on their pretest essay as “low prior knowledge” (LPK) and students that received a 3-5 as “high prior knowledge” (HPK). This cutoff was chosen because a KI score of 3 must include at least one normative scientific idea, while a score of a 2 does not.

CYSTIC FIBROSIS

Sarah and Michael are going to have a baby.

Both of them are completely healthy, but they know that Sarah's dad (the baby's grandfather) has a genetic disease called **cystic fibrosis (CF)**, which affects the lungs.

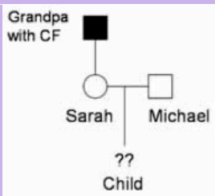


Is it possible for the child to be born with the disease, Cystic Fibrosis? Explain your answer.

It is possible because the Grandpa has the disease.

CYSTIC FIBROSIS - Revise your Ideas

Look at the diagram below again.



In order to have cystic fibrosis, the Grandpa would have to have **two recessive alleles: f f**

Think about what alleles Sarah would have to have.

Use the information above to **revise** or **improve** your answer by **adding information** or making your ideas more clear.

It is possible because the Grandpa has the disease.

Figure 3: Pre/post revision assessment item: initial prompt and revision prompt

Table 2. KI Rubric Example: Why do siblings from the same parents look similar but not exactly the same?

KI Score	Description	Examples
1	No Answer	“I don’t know”

2	Non-normative/irrelevant: Token mechanism only ("skips a generation") with no elaboration. Incorrect ideas: "you get different amounts of DNA from each parent"	Because you and your sibling have close genes but they are not the same genes. You inherit similar amounts of the same traits from the same parents at slightly different amounts. Because it's not exactly the same, you look a little different.
3	Partial link (one correct statement, but not connected to other scientific ideas, or student does not elaborate)	They get different parts of dna from their parents. You get a different set of genes then your sibling.
4	One full link between normative scientific ideas	Because you get half of your parents DNA but it does not specify which half you will inherit from them. This means that the half that you might get will not be the same that your sibling will get.
5	At least two full links	Siblings do not look exactly the same because they have slightly different alleles. Each child has a chance of receiving a different allele from its parents than its sibling because of probability.

Qualitative revision codes were also given to the embedded essay revisions and pre/post revision item based on how a student revised. A code was given for whether students made connected (C) or disconnected (D) revisions. Another code was given for whether students added new (N) ideas in their revision or expanded existing (E) ideas that were already present in their initial response (see Table 3 for examples of each code combination). These parameters were chosen to assess whether students were integrating new information with their prior knowledge (connected/new), which is the primary goal of the knowledge integration framework. The KI framework promotes the idea that making connected revisions with new ideas (C/N codes) is consistent with better learning.

Table 3: Rubric and examples for embedded essay revisions (Student revisions underlined)

Initial Response	Revision (underlined section is changed)	Revision Score	
		Connected (C) / Disconnected (D)	New (N) / Expanded (E)
You would use the method of counting by 25's. Each square is a 25% chance.	You would use the method of counting <u>by quarters</u> . The two letters from each parent <u>would represent a quarter of the genotype and all the quarters combined would show what phenotype would be dominant over the other.</u>	C	N
A method I would use is that I would choose the number of squares that have a certain genotype and find out what percent of the squares have that genotype.	A method I would use <u>to calculate the probability of getting a certain genotype</u> is that I would choose the number of squares that have a certain genotype and find out what percent of the squares have that genotype.	C	E

You would put the alleles of each parent on the outside of the square and the possible alleles for their children would be in the square.	You <u>can</u> find the dominant and recessive traits to calculate the probability out of <u>four</u> .	D	N
The figure shows how many possible genotypes that children can have.	The figure shows how many possible genotypes that children can have. <u>D means dimples and d means no dimples.</u>	D	E

Results

Pre/posttest analysis

All students improved in KI score from pretest (mean=1.89) to posttest (mean=2.61) [$t(152)=9.66$; $p<0.001$]. This suggests our curriculum effectively taught genetics concepts. Condition had no effect on learning gains when considering all students.

Examining the pre/post revision item, we found that students' revision gain score improved significantly from pre to posttest, regardless of condition [$t(86)=4.40$; $p<0.001$]; students gained, on average, only 0.02 points from their revisions on the pretest, but gained 0.62 points from their revisions on the posttest. This suggests we helped students improve their ability to revise their scientific ideas after encountering new evidence.

When comparing student learning based on prior knowledge, as defined earlier in this paper, we found that LPK students gained an average of 0.56 points more than HPK students from pretest to posttest [$t(152)=2.17$; $p<0.05$] across both conditions. This means that our curriculum especially supported LPK students in learning new science concepts since they were able to add more new ideas to their responses, as reflected by higher knowledge integration gains.

We also found that LPK students revised by adding new ideas more often on the posttest than in their pretest revisions [$t(143)=3.82$, $p<0.001$]. There was no pre/post difference for HPK students, indicating that the curriculum more specifically supported LPK students in adding new ideas.

Embedded Revision Analysis

When we examined student work within the curriculum unit, we found once again that all students improved from initial to revised score on both the *Siblings* item [$t(175)=4.19$, $p<0.001$] and the *Punnett Square* item [$t(175)=5.90$, $p<0.001$], with an average gain of about 0.20 points on each.

Again, interesting differences presented between LPK and HPK students, with interactions between conditions. The *text* annotator provided the greatest advantage on the *Siblings* item for LPK students; they revised 2.64 times as often as those in the *model* condition [$z(98)=1.99$, $p<0.05$], while condition had no effect for HPK students on this question. For the *Punnett Square* question, there was no effect of condition or prior knowledge for either LPK or HPK students.

On the *Siblings* item, students in the *text* annotator condition were more likely to revise by adding new ideas; they added new ideas approximately 2.94 times as often as students in the *model* annotator condition [$z(175)=2.40$; $p<0.05$]. Students in the *text* annotator condition were also 2.11 times as likely to make connected revisions, though this was not significant at the 5% level [$z(118)=1.53$, $p=0.13$]. For the *Punnett Square* item, condition had no effect on the types of revisions students made.

For the *Siblings* item, LPK students in the *text* condition were 2.58 times as likely to revise by adding new ideas as compared to LPK students in the *model* condition [$z(155)=1.97$; $p<0.05$]. HPK students did not differ in terms of adding new ideas based on condition. For the *Punnett Square* question, neither condition nor prior knowledge had an effect.

Similarly to the pre/posttest, on the embedded *Siblings* item HPK students were 4.54 times as likely to revise in a connected way as compared to LPK students [$z(169)=2.53$; $p<0.05$]. Similarly, on the *Punnett Square* question, HPK students were 3.43 times as likely to revise in a connected way [$z(169)=2.13$; $p<0.05$]. Our curriculum not only supported LPK students in adding ideas, but helped HPK students successfully connect their knowledge to new science content.

We also investigated the effect of students' embedded revisions on their pretest to posttest gains. We found that students who made any revisions at all on the embedded question achieved an average revision gain score of 0.33 points higher than students that did not revise at all during the unit [$t(118)=6.65$; $p<0.001$]. In addition, making connected revisions on the embedded revision questions resulted in, on average, a pre to posttest gain of 0.44 points more than students that did not make connected revisions on the embedded assessment questions [$t(152)=2.10$; $p<0.05$]. This suggests that practice making connected revisions during the unit resulted in increased pre/post learning gains.

Overall, our curriculum was effective at teaching students genetics concepts, especially students with low prior knowledge (LPK). Significantly, our revision pre/post item revealed that students improved their revision skills by practicing revision throughout the unit. This revision practice, for those who chose to revise during the unit, also resulted in significantly higher learning gains. In terms of adding new ideas, LPK students benefited more from annotating the essay in the *text* condition than parsing through evidence in the *model* condition; this suggests that LPK students didn't necessarily need to gain more ideas from the models in the unit, but needed help with how to organize the expression of their ideas. Perhaps the *text* condition supported LPK students by making the revision process more visible.

Conclusions and Implications

This study reveals that students can improve their understanding of genetics as well as their ability to revise their ideas after encountering new evidence. Engaging in integrated revision during instruction is connected to significantly greater pre to post learning, supporting our KI perspective that making connections is a powerful learning strategy. Students coming in with more knowledge (HPK) are at an advantage when asked to make connections with new material (and therefore make more connected revisions), but our *text* annotator activity successfully supported low prior knowledge students to improve their revisions by adding more new ideas.

The goal of comparing these two guidance conditions was to distinguish what types of support students need most in terms of revising their ideas. The *model* annotator activity was designed with the goal of helping students better interpret the results of the models and gain more ideas from evidence. However, the *text* annotator condition was more effective in guiding students to add more new ideas to their revised explanations. This reveals that students, especially LPK students, perhaps need less guidance directed toward helping them interpret model output and instead need help distinguishing which of their ideas are relevant for their explanations. The *text* annotator can help students distinguish their ideas by making the revision process more visible. By annotating an essay with vague ideas about genetics, students can visualize how to take a written explanation and change parts of it to make ideas more explicit, use of scientific vocabulary more accurate, and connections between genetic phenomena more apparent. The success of the *text* annotator activity in encouraging addition of new ideas suggests that students need explicit help with how to revise and what that looks like. Future studies will incorporate this finding and further investigate how this activity encourages better quality revisions.

When asked to revise, as discussed earlier in this paper, students tend to make only surface-level changes to their essays instead of improving complex ideas or content, if they revise at all. Our *text* annotator activity encouraged students to revise more often, and supported LPK students in adding new scientific ideas, thereby changing the actual content of their scientific explanations. The Knowledge Integration framework purports that integrated understanding can only be achieved through constant revision of knowledge, continually connecting new ideas to your current understanding, which is itself always evolving with experience. This process involves adding new information, but, just as importantly, it involves sorting through and distinguishing between ideas and how they connect with each other. Traditional instruction tends to suppose that students, especially those with low prior knowledge, need more information in order to progress, but our results suggest that modeling the revision process to support how their relevant ideas connect is more beneficial.

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